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DEVELOPMENT OF MULTI-FUNCTIONAL SHIPBOARD INCINERATOR.(U)

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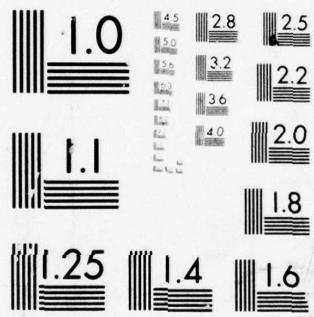

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Vent-O-Matic Incinerator Corporation
North Quincy, Massachusetts

409617

DEVELOPMENT OF MULTI-USE SHIPBOARD INCINERATOR

NAVSEA Contract No. N00024-75-C-4199

See AD A028 444

PHASE II

FINAL REPORT

Data Item B003

See 1473

March 1, 1977

APPROVED FOR PUBLIC RELEASE -
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Noise Report from Bolt, Beranek and Newman, Inc.
Dated January 20, 1977

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SECTION I
GENERAL

1.0 Report Organization

This Final Report covers Phase II, from its inception to shipment, of the development program for a Multi-functional Incinerator (MFI System) under Contract No. N00024-75-C-4199. This contract was awarded by Naval Sea Systems Command to Vent-O-Matic Incinerator Corporation, North Quincy, Massachusetts, on September 20, 1974, with Phase II being funded as of April 2, 1976.

The Final Report contains review of the Phase II development work, test results and a discussion of remaining problems of the MFI prototype as of the shipment date, February 18, 1977.

2.0 Schedule

The major tasks and actual dates of the Phase II program were as follows: (The Phase I durations are shown in comparison)

Task	Completion	Phase II	Phase I
Design, incl. dwgs	Aug. 31, 1976	22 weeks	22 weeks
Build Prototype	Oct. 15, 1976	6 weeks)	9 weeks
Instal on test stand	Nov. 02, 1976	3 weeks)	
Shake-down tests	Feb. 11, 1977	14 weeks	11 weeks
Disassemble & ship	Feb. 18, 1977	1 week	1 week
Final Report	Feb. 28, 1977		
Phase II Duration to Ship		46 weeks	

The Phase II program extended over forty-six weeks to ship. This period included design, testing and modifications. It is interesting to note that the Phase I tasks covered almost exactly the same duration. The reason was that, contrary to the original expectations, Phase II consisted essentially of a new development effort, based on a major redesign.

3.0 Operating Time

The MFI prototype was operated for the following time periods before shipment from the Vent-O-Matic facility:

1 Curing Cycle (Nov. 2, 1976)	48 hours
25 Shake-down Tests (Nov. 8, 1976 to Feb. 11, 1977)	125 hours
Average Test Duration	5 hours/test

The test duration is the total operating period including preheat and burn down. Tests included the burning of dry and moist waste paper, shredded paper, wood, rags, potatoes, sewage and waste lubricating oil. The shortest test run was two hours and the longest ten hours ten minutes.

SECTION II
PERFORMANCE ACHIEVED

1.0 Review of Test Series

1.1 Curing

After assembly of the prototype, the refractory lining was subjected to a forty-eight hour curing cycle. The fuel used was No. 2 fuel oil and control was excercised by setting the firebox temperature controller according to a previously agreed schedule. The heating cycle is shown on Fig. 1, which represents the recorded firebox temperature (^{o}F).

1.2 Shake-down Tests

Some 24 tests were conducted to evaluate the system and make the necessary modifications. These tests are summarized in Table 1. The corrections and adjustments made are described in Section IV.

The prototype was tested with solid refuse consisting of various mixtures of:

- dry shredded paper (fine)
- moist shredded paper (coarse)
- wood
- rags
- books
- household bagged trash

Sewage was simulated by adding 2.85 lb. urea and 30 lb. "Instant Ocean Salt" per 100 gal. of freshwater. Waste oil consisted of 219 TEP lubricating oil. Auxiliary fuel used was No. 2 fuel oil.

2.0 Operational Parameters

As a result of the test program, a set of operating parameters were established as listed in Table 2. From the viewpoint of equipment performance, the most significant conditions may be summarized as follows:

(a) Feeding of Solid Waste:

The solid waste cycle consists of two 4-minute charging periods per hour 30 minutes apart. During this 4-

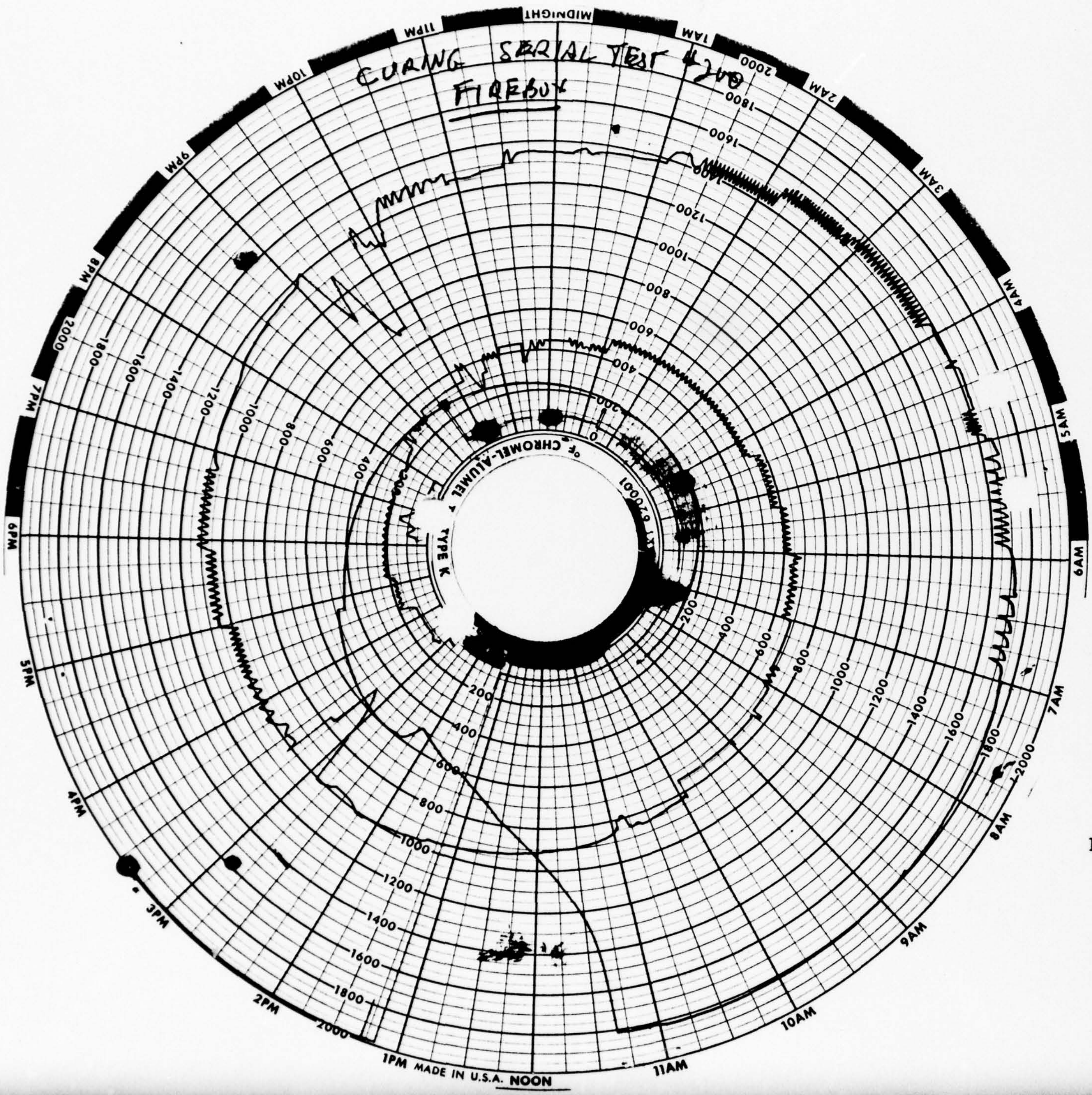

Fig.1: Curing Cycle - Firebox Temperature

Table 1: Summary of Shake-down Tests

Test No.	Date	Objective	Waste Material	Charges Per Hr	Burn Rate Per Hr	Oper'g Time Hrs	Preheat to Set Point Minutes	Burn-down (1) Minutes	Remarks
200	11-03-76	Curing Refractory	None			48:00	-	-	
201	11-08-76	Obtain Basic Data	Paper & Wood			2:00	-	-	
202		Check Fans							
203	11-09-76	Evaluate Draft	Paper			3:20	-	-	
204	11-11-76	Effect of U/F Air				2:37	23	27	Natural draft OK
205	11-12-76	ID Fan Speed: 3100 RPM	Sewage			4:45	19	-	Fan speed increased to 3100 RPM
206	11-15-76	Set Point: 1600F	Sewage & Paper		46 gal.	2:00	-	-	
207	11-16-76	Effect of Stack Damper				4:30	-	-	Keep damper 1/2 closed during start up
208 209	11-17-76 11-18-76	Smokeless Charging Smokeless Charging	Paper 1/3 Paper 1/3 wood 1/3 rags	1x60# 4x30#	60 lb 120 lb	5:15 5:12	32 35	-) -)	Smoke reduced with smaller charges
210	11-19-76	Sewage @ 1600F St. Pt.	Sewage		46 gal.	7:13	35	60	Cannot Maintain temperature
211	11-22-76	Smokeless Charging	Paper	2x60#	120 lb.	8:30	43	53	
212	11-24-76	Effect of Afterburner				4:00	-	-	A/B questionable
213	12-16-76	Simulate Operation	4/5 Paper, 1/5 wood	3x40#	120 lb.	6·45	30	75	Installed splitter vanes
214	12-21-76	Full Day Operation	1/2 Paper, 1/2 Potatoes	3x40#	120 lb.	10:10	30	79	OK
215	12-27-76	Sewage Operation	Simul. Sewage		50 gal.	3:20	30	-	Drilled 10-1/2" holes in A/B outer casing

(continued)

Table 1: Summary of Shake-down Tests (continued)

Test No.	Date	Objective	Waste Material	Charges Per Hr	Burn Rate Per Hr	Oper'g Time Hrs	Preheat to Set Point Minutes	Burn-down (1) Minutes	Remarks
216	12-29-76	Refuse + Sewage	Paper/Wood Sewage	1x120#	120 lb) 46 gal)	3:55	30	60	Sewage Chbr. on Temp. Cont.
217	1-03-77	Smoke Test	Dry Shredded Paper			2:45	34	-	A/B removed
218	1-07-77	Smoke Test	Dry Shredded Paper			4:25	26	60	Need max. air
219	1-13-77	Navy Demonstration	Refuse, Waste Oil & Sewage	3x40#	120 lb) 42 gal)	8:30	25	60	OK
220	1-14-77	Overload Test	Refuse	180#/10 min.	40 gal				
221	1-17-77	Effect of A/B on Smoke	Refuse	3x40#		4:40		80*	A/B reinstalled
222	1-18-77	Burning of Wet Paper	Wet Paper	3x40#	120 lb	4:18	-	85*	A/B removed
223	1-21-77	Capacity with Garbage	50% Paper, 50% Potatoes	2x60#	120 lb	8:20	37	140*	
224	1-26-77	Evaluate Feed Cycle	Dry Shredded Paper			2:40	-	-	60# of 4x15# charges in 3-1/2 min, 3 strokes/chg
225	2-02-77	Evaluate 3-Stroke Cycle	Moist Paper, Potatoes	2x60) 2x30)	92 lb	8:05	22	85	OK

(1) Shut-off Temperature = 600F except where marked (*) 400F

minute "time window" solid waste may be charged at the maximum permissable rate. Each automatic feed cycle consists of one feed stroke plus two half strokes and takes 17 seconds. Since charging the feed hopper takes some 20 seconds, each complete charge per feed cycle requires 40 seconds. Each 4-minute charge window, therefore, will allow up to 6 complete cycles.

The weight of solids that may be fed into the firebox per cycle, can vary from 8 lb for loosely bagged trash to 50 lb for books or garbage. This means that during each 4-minute charge window some 50 lb to 300 lb could be charged depending on the density of the material.

Since the daily amount of material and its various components is fixed, the weight of material that can be charged tends to be self-limiting.

(b) <u>Firebox Temperature</u>

The set point for the firebox temperature has been set at 1600F for all types of solid waste provided no sewage is burned.

(c) <u>Sewage Rate</u>

When burning sewage, temperature control is automatically shifted to the sewage chamber thermocouple, which is set at 850F. At that temperature, sewage appears to be completely vaporized and incinerated and no odor problem is anticipated. The firebox temperature is allowed to float while burning sewage and may reach 2000F.

(d) <u>Preheat</u>

The control system does not permit the burning of any wastes until the set point temperature of 1600F is reached. During this time, the flue gas damper is kept at half-open. Under these conditions, some 30 minutes are required until set point is reached and the unit switches automatically to OPERATE.

(e) <u>Burn-down</u>

After completion of charging wastes, the unit is turned to BURN DOWN. The fans run to burn up any remaining

Table 2: Operating Parameters - 1-25-77

Circulating Oil	Burner Off		Burner On	
	#2 Oil	TEP	#2 Oil	TEP
Pump Suction	1" Vac	7" Vac	1" Vac	7.0" Vac
Pump Discharge	15 Psi	21.5 Psi	16 Psi	20.0 Psi
Burner Delivery Pressure	12 Psi	10.0 Psi	11 Psi	10.0 Psi
System Return Pressure	2 Psi	1.0 Psi	.5 Psi	2.0 Psi
Oil Pump Motor 115V Ø	4.5 Amps			
Main Burner				
Pump Inlet - No Fire	11 Psi	8.9 Psi		
Pump Inlet - Lo Fire			11.0 Psi	9.0 Psi
Pump Inlet - Hi Fire			10.0 Psi	8.0 Psi
Atomizing Air - No Fire	6.5 Psi	6.5 Psi		
Atomizing Air - Lo Fire			8.0 Psi	7.0
Atomizing Air - Hi Fire			11.0 Psi	10.0
Firebox Temp. Stg.* - 1600°F				
Firebox Shut-down Temp. - 400°F				
Timer Stg. - Burner Off After Last Feed - 2 Min.				
Burner Secondary Air Shutter - FIXED OPEN				
	#2 Oil	TEP		
Flame Safe Volts - Lo Fire	5+	5-		
Flame Safe Volts - Hi Fire	6+	5+		
Burner Motor 440V 3Ø	0.9 Amps			
Sewage System				
Nozzle Cooling Air Pressure - 2-3 Psi				
Atomizing Air Pressure - 17 Psi (Should be 23 Psi)				
Pump Transmission Stg.*- 10.0 (42 Gph)				
Spray Chamber Control Temp. Stg.*- 850°F				
Firebox Permissive Temp. - 1600°F				
Sewage Pump Motor 440V 3Ø 0.5 Amps				

* Setting

(continued)

Table 2: Operating Parameters - 1-25-77 (continued)

Ash Door Operation			
Open Time	-	1-2 Secs	
Close Time	-	2 Secs	
Time to Operation	-	28 Mins	
Operating Count	-	1 per 28 Min on 1st Ram Feed	
Solid Feed System			
Door Up Time	-	3 Secs	
Door Down Time	-	2 Secs	
Ram Feed	-	4 Secs	
Ram Return	-	4 Secs	
Auto Cycle Time	-	17 Secs	1 Feed Stroke + 2 Half-Strokes
Time Stg* - Ram VAM	-	4.5 Secs	
Time Stg* - Door VAM	-	17-19 Secs	
Feed Cycle = 40 Secs	Feed Window = 4 Mins		
Dampers			
Undergrate No. 1	-	Closed	
Undergrate No. 2	-	Open	
Ash Door	-	Half-Open	
Combustion Air	-	Open	
Cooling Air	-	Open	
I.D. Fan Discharge	-	Open (After 1600°)	
I.D. Fan Discharge	-	Part Closed (Start up to 1600°)	
Draft Conditions - Start up - Burner Off - I.D. Damp Half-closed			
		In. -H_2O	
Undergrate Static	-	- 0.6	
Firebox	-	- 0.65	
I.D. Fan Inlet	-	- 1.8	
I.D. Fan Out	-	+14.0	
Fly-ash Coll In	-	+ 7.5	
Fly-ash Coll Out (Stack)	-	+ 0.8	
Comb Air Fan Out	-	+ 1.6	
Cooling Fan Out	-	- 1.0	
Jacket Air Static	-	- 0.9	
I.D. Fan Motor 208V 3 Ø	-	26.5 Amps (Damper Open, Hot)	
Cooling Fan Motor 440V 3 Ø	-	1.9 Amps	
Comb Air Motor 440V 3 Ø	-	1.05 Amps	

* Setting

charge and cool the unit until the preset shut off temperature is reached. The time period depends on where this temperature is set. It is presently set at 600 F and the burn down period takes about 90 minutes.

(f) Ash Removal

The ash door is automatically opened twice an hour on the first charge cycle following the lapse of a 30 minute time period. It stays open for one complete charge stroke. Ashes are dropped into two ash drawers which may be removed after cooling before starting the next burn cycle. Ashes left on the grate, remain there.

3.0 Noise Level

Noise level measurements were taken of the unit during the shake-down test period. After covering of the oil pump set, the sewage pump, the induced draft fan and fly ash collector with Owens Corning Fiberglas 2 in. Flexoround thermal insulation, satisfactory noise level was achieved. The test results are shown in the appended report dated January 20, 1977.

SECTION III
EQUIPMENT FAILURE & CORRECTIVE ACTION

1.0 Induced Draft Fan

On installation of the Chicago Blower size II heat fan, it was found that its output was lower than rated. Fan speed was increased from 2636 RPM to 3100 RPM by changing motor sheave from 8.2 in. P.D. to 10.0 in.P.D. This change produced the desired draft capacity.

After acoustically lagging the fan and operating several times, smoke was noted coming from under the lagging intermittently and the fan bearings became noisy. Bearing temperatures were running over 200°F, and it was impossible to keep grease in them. Fan gas temperatures, in general, did not exceed 600°F (fan rated at 800°F). One week later, lagging was removed and the following observations were made:

(a) Fan paint completely deteriorated.
(b) Fan inlet nozzle plate warped between bolt holes (8) on wheel periphery.
(c) Nozzle seal material burned and blown out.
(d) Heat from fan casing blowout had evidently been channeled over the bearings by the lagging.

Manufacturer's representative conceded that paint was good only for 450°F and that RTV type inlet plate seal had been erroneously used. Factory agreed to bear some part of the repair cost.

VOM straightened plate, added eight more mounting bolts and sealed assembly with asbestos cement. Unlagged testing proved that repair was leak tight and bearing temperatures were reduced to 170°F maximum. VOM subsequently added small auxiliary bearing cooling fan to ensure that bearing temperatures remained under 140°. Fan operation was trouble free thereafter.

During fan repair interval, it was decided to install turning vanes (curved 3/16" plate) in the cooling duct outlet, the fan suction plenum and fan discharge rectangular elbow. It was felt such vanes would increase fan capacity. While improvement in draft was noted, it was also apparent that the cooling duct vane was interfering with the turbulent mixing action of the two gas streams. A several hundred degree difference was noted from one side of the fan suction vane to the other. While no adverse condition has resulted from this effect, the

cooling duct turning vane was removed before shipment but the plenum vane was retained.

2.0 Front Face of Firebox Shell

In an attempt to shorten the cooling down period after a test run, the feed door was unwisely left open during burn down. Heat, soaked into the door refractory, was transferred into the upper front firebox metal panel causing it to expand and to take a bowed out permanent set, interfering with the feed door. Forces were such as to partially retract anchors from the refractory.

The interference condition was remedied by forcing the bowed section in against the refractory (with a fork lift truck), cutting rectangular holes in the panel and welding the hole edges to the then exposed channel member of the adjacent roof slab. The opened roof slab recess was then sealed with asbestos cement. This repair is expected to remain effective but some ultimate solution to the above described contingency seems necessary. (See Section V, para 2.2)

3.0 Feeder Lid

The outboard feeder lid support bracket was damaged several times by operating the ram with the lid open. The bracket was easily bent into shape and recurrence is now prevented by a lid-actuated, feeder lockout limit switch.

SECTION IV
OPERATIONAL PROBLEMS AND CORRECTIVE ACTION

1.0 Preheat Period

To obtain adequate sewage burn and smokeless combustion of solids, it was found necessary to preheat the unit. Furthermore, it was observed that the preheat period could be limited to 30 minutes by reducing the draft during this stage. This was done by setting the stack damper in such a position that on reaching the firebox control temperature, firebox draft was slightly negative (-.05 in v.g.).

The automatic control system was consequently modified as follows:

- On start up, the unit is preheated with Diesel oil, all waste feeds are locked out and the stack damper is half closed.

- On reaching firebox temperature set point (1600 F), the damper is automatically opened and the waste feed lockouts are released.

2.0 Smoke Emission

Smoke emission from the stack was observed at various times. To determine the factors effecting smoke, a series of tests were run (test #'s 217, 218 and 221) using a single 40 lb charge of dry shredded paper at a time. The following conclusions were drawn:

(a) Maximum smoke emission occurs immediately after charging when the volatiles are driven off at a high rate.

(b) The use of overfire air proved to be an effective means of reducing smoke. Overfire air is provided by-

- the overfire air jets located in the roof of the firebox.

- the oil burner combustion air. During this period, the oil supply is shut off (for some two minutes) but the oil burner air is kept open to provide additional overfire for the consumption of smoke.

(c) No visible effect on smoke due to the afterburner could be determined, either by the use of burner air or burner flame. For this reason, the afterburner was removed.

(d) Charging "little and often" produces less smoke. Four ten pound charges produced less smoke than one forty pound charge.

(e) A cold furnace produces more smoke than a heated furnace.

The following operational settings were made as a result of the above conclusions-

- keep oil burner damper fixed open;
- use maximum available overfire air;
- afterburner is not required;
- preheat furnace before feeding solids.

3.0 Feed Control

3.1 Analysis

Throughout the testing of both Phase I and Phase II prototype, control of the rate of charging has been exercised by the test crew according to the test plan. When the rate of burning was lower, overfeeding occurred; when it was higher, inadequate use of available capacity resulted.

The rate of burning with mixed refuse (50% paper, 50% potatoes) was demonstrated to be 130-135 lb/hr over 6 to 8 hours of feeding (Test No. 214 and 223) whether charging twice or three times per hour. When burning garbage (100% potatoes), Test No. 225 indicated that this can be done at 60 lb/hr.

The hourly rate of charging must be equal to or less than the rate of burning but, to prevent "overstuffing" the firebox, the rate of charging at any one time is constraint by the "active" volume of the firebox. The active volume, defined as the grate area multiplied by the height of the door opening, is 14 cft and represents the maximum volume of refuse which may be charged at any one time. The feeder hopper has a volume of 3.6 ft. If it is assumed that 90% of the feeder volume is utilized, the firebox when empty can accept four feed strokes (4x3.2=12.8 cft) of refuse without compaction.

While burning, the firebox can accept an additional load any time the active volume has decreased by an amount equivalent to the feed hopper volume (3.2 cft). This method of feeding, however, would require frequent operator attention. It may be regarded as "semi-continuous" and from a combustion point of view, would give optimum conditions, viz., higher burn rate and no smoke.

An alternate method is "semi-batch" feeding which would allow each full load to burn down completely before recharging. This procedure would reduce operator attention by the extended burn period. However, burn rates will be somewhat lower with a greater chance of smoke emission after charging.

Since the hourly capacity of the incinerator is specified by weight, the volumetric relationship described above must be modified by the density of the material to be burned. Solid waste densities vary over a wide spectrum, such as bagged loose trash at 2 lb/cft to garbage or books at 50 lb/cft. While the feeder is basically a volumetric device, its weight is uncontrolled.

This situation presents a unique control problem. In an attempt to quantify it, Table 3 was prepared for the range of material to be handled. It is seen that the weight per charge (one full feeder hopper) varies from 6.5 lb for boxes to 162 lb for books (Column 3). Assuming a burn rate of 120 lb/hr for loose trash and refuse, and 60 lb/hr for all others, the burn time for each charge varies from 6.5 minutes to 162 minutes.

In other words, in the semi-continuous mode, the incinerator may be charged every 6.5 minutes with low density boxes or trash, or every 2 to 3 hours with high density materials. Normal refuse with a density of 10 lb/cft may be charged once every quarter hour.

In evaluating the batch mode of feeding, it should be understood that the firebox can accept no more than four full charges at a time (without compression). Column 9 shows how often the incinerator unit be charged per hour to meet the specified burn rate and Column 10 shows the interval between charges. It is seen that for solid wastes (other than garbage and books), loading can be performed in 20 to 40 minute intervals (depending on density) with each load consisting of four charge strokes.

Table 3: Relationship of Charge Rate with Type of Waste

Item (1)	Type of Waste (2)	Density lb/cft (3)	Weight per Charge lb (4)	Burn lb/hr (5)	Rate lb/min (6)	Burn Time per Charge minutes (7)	Number of Charges per hour (8)	Semi-Batch Loads per Interval hr (9)	mins (10)
1	Boxes	2	6.5	60	1	6.5	8	2	30
2	Trash (bagged)	3	9.6	60	1	9.6	6	1.5	40
2A	Trash (bagged)	3	9.6	120	2	4.8	12.5	3	20
3	Trash (loose)	5	16	120	2	8	8	2	30
4	Refuse (light)	6	19	120	2	9.5	6	1.5	40
5	Refuse (heavy)	10	32	120	2	16	4	1	60
6	Garbage	40	130	60	1	130	-	-	
7	Books	50	162	60	1	162	-	-	

Notes per Columns:

(2) assumed
(3) based on 90% use of feed hopper or 3.2 cft
(4) (2) x 3.2
(5) as specified
(6) (5)/60
(7) (4)/(6)
(8) 60/(7) rounded off upwards
(9) (8)/4 where max. charges = 14 cft/3.2 cft = 4 per load
(10) 60/(9)

3.2 Feed Control

The design of any feed control scheme should meet the following objectives with any material:

(a) utilize the maximum burn capacity of the incinerator;

(b) prevent overfeeding the firebox;

(c) allow charging within the specified operation time of 5 minutes per hour.

As borne out by test experience, the data of Table 3 indicates the need for a complex control system to cover the widely varying conditions. In an attempt to simplify the feed control, the following basis was assumed:

(a) books, garbage are regarded as exceptions;

(b) the cycle time per charge is 40 to 50 seconds including hopper loading and feeding;

(c) select a time interval between loads as 30 minutes.

These assumptions suggest two alternate control approaches:

(a) control the maximum number of charge strokes at 4 for each load cycle.

(b) control the maximum charge time for each load cycle.

If the charge strokes are controlled at 4 per load cycle (alternate (a)), the hourly feed rate could vary from 52 lb for boxes to 256 lb for refuse. The lighter materials (boxes and trash) could only be loaded - and burned - at 52 to 77 lb/hr. The denser material, on the other hand, would require some two hours to burn down and an attempt to charge 4 strokes after 30 minutes would result in failure.

In order to control this situation, it was decided to limit the charge time per load cycle (alternate (b)) rather than the number of strokes. The charge time is so selected that the firebox can be fully loaded (4 charge strokes) every half hour

with all materials. In the case of heavy refuse, several attempts by the operator will be required after the first half hour, to feed into an overstuffed firebox and the timer will run out before further attempts are made. The time "window" suggested is 3-1/2 minutes or 210 seconds which would allow 4 - 45 second charges plus 30 seconds to spare.

Although the prototype was shipped with this control scheme (the "window" timer) for testing, further improvements are desirable. See para 1.0, Section V, for a proposed scheme.

3.3 Burn Down

To reduce operator attendance, the MFI System includes an automatic shut off control. After introducing the last charge, or at the end of the desired sewage burn, the operator switches to BURN DOWN and can leave the compartment. The oil burner is turned off automatically and the incinerator shuts down when reaching a preset firebox temperature.

The purpose of the burn down period is twofold:

(a) to burn down the last solids charge;

(b) to cool the unit to a safe temperature. The heat stored in the heavy refractory would otherwise cause excessive temperature excursions.

The shut off temperature set point is so selected that the surface temperatures will remain below the specified limit of 150 F.

However, the lower the shut off temperature, the longer the burn down period. Test results indicate that 600 F shut off temperature results in a burn down period of 1-1/2 hours. After shut off, firebox temperature rises to 750 F before dropping. While equipment appears to be safe, jacket temperature, however, have been observed to rise to 200 F (Test No. 225). Safe limits were maintained when setting the shut off temperature to 400 F but the burn down period extended to 2 hours 20 minutes (Test No. 223).

3.4 Daily Operation

An analysis of the daily operation cycle was made in view

of the various modifications and settings described above. Fig. 2 illustrates a complete daily operation burning solids, sewage and waste oil.

The following operating conditions may be defined:

Time Hrs.	Duration	Activity	Rate
0	-	Start System	-
.5	30 Min.	Clean ashes, check oil	-
1.0	9 hours	Feed solid waste burn sewage burn waste oil	120 lb/hr 42 gph as req.
9.5	1-1/2 to 2 hours	Burn down	-
11.0	-	Automatic shut off	-

It may be seen that operator attendance will be required for 9-1/2 hours while the system is in operation for some 11 hours.

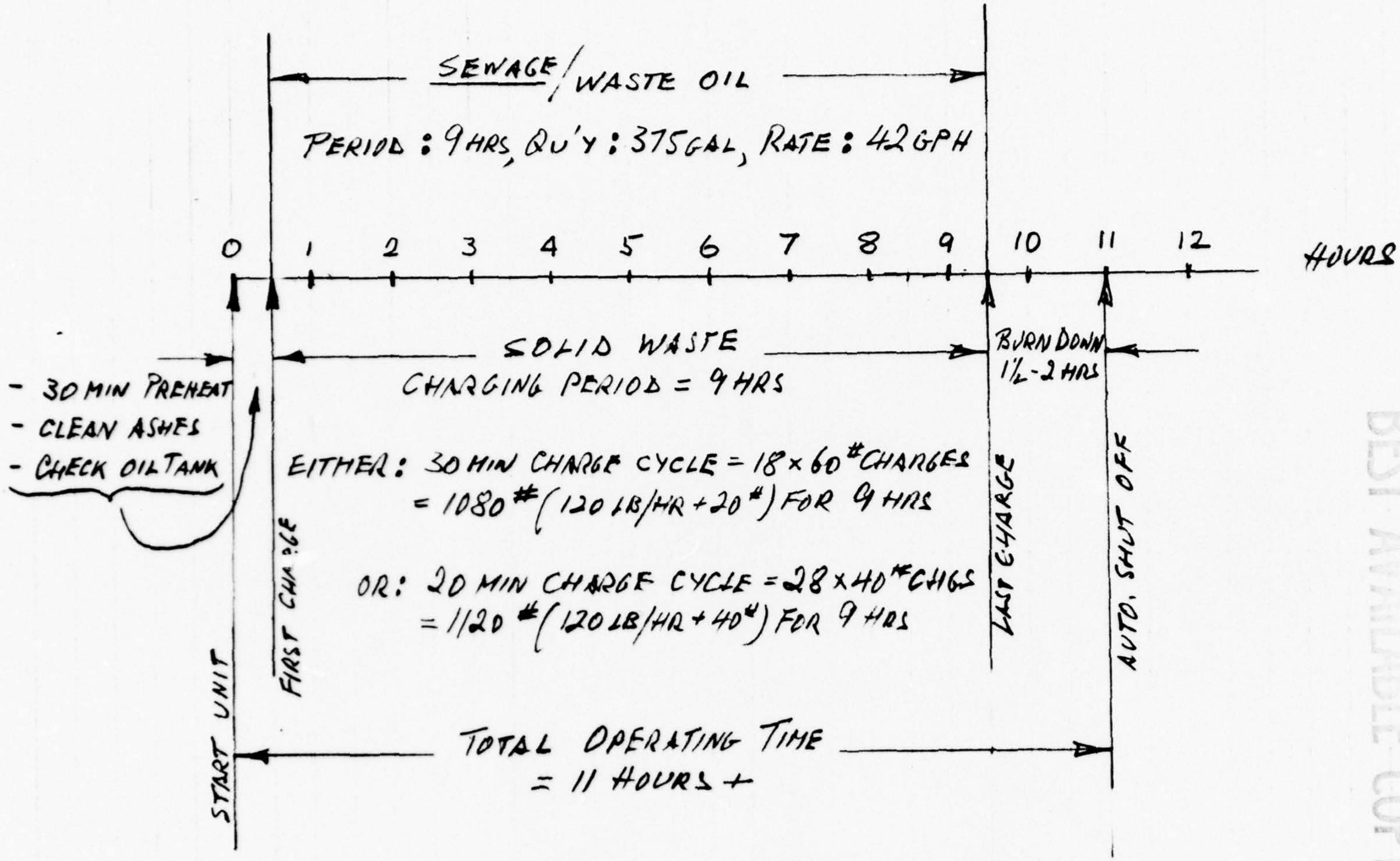

FIG 2: PROPOSED OPERATING CYCLE (REV. 1)

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SECTION V
STATUS OF REMAINING PROBLEMS

1.0 Feed Control

As described in para 3.0, Section IV, the feed control requires further study. A number of options exist, the selection of which depends on further experience during the planned formal testing.

1.1 Add/Subtract Counter

The disadvantage of the "window" timer scheme is the lockout period between charging. No solid waste can be fed for some 25 minutes between the end of one load cycle and the beginning of the next. To eliminate this problem, a control scheme is proposed which would utilize the individual burn times (Column 7, Table 3, Section IV) and the active firebox volume. In this scheme, an add/subtract counter is used in conjunction with a timer. The counter is set at 4 (representing the maximum number of permissible charges) and the timer at a suitable period selected from the above referenced table. A period of 7-1/2 minutes is suggested. Everytime a charge is introduced into the firebox, one count would be deducted from the counter setting of 4, while every 7-1/2 minutes the counter would be advanced by 1 count (up to the maximum of 4).

This scheme would allow considerable flexibility. During start up, the feeder is locked out by the temperature controller. During the 30 minutes of preheat, the timer would set the counter to 4. At that time, batch loading (4 charges) can be performed which would set the timer to "0" and lock out the feeder until 7-1/2 minutes have elapsed (from the start of the first load). One charge may be introduced at that time. If no charges are made, the counter would continue to release charge cycles. After 15 minutes, 2 charges may be made, after 22-1/2 minutes - 3, and at the end of 30 minutes, the full count of four charges are available.

While this system provides considerable more flexibility than the "window" timer, it still does not solve the problem of heavy materials. At four charges every half hour (or 8 charges per hour every 7-1/2 minutes), 256 lb of refuse could be loaded compared with a maximum burn rate of only 120 to 130 lb/hr.

1.2 Other Control Signals

Because of the potential problem with material of heavy density, the control system described above must either be "trimmed" with another signal or another method must be substituted.

Other than relying on operator judgement, the following control methods are worthy of further study:

(a) Firebox draft as a measure of firebox capacity: Test data indicate that firebox draft can be a measure of the active firebox volume available to accept further charges.

(b) Load cells or grate: A measure of the weight of material on the grate, may be used to release feeder.

(c) Load cells on the feeder: A measure of the weight to be charged into the firebox, may be used to compare with residues of firebox to accept fresh charge as measured by (a) or (b).

It is suggested that continuous measurements be made of firebox draft and that detailed records be kept to evaluate its effectiveness.

2.0 External Casing Temperatures

Variances above the specified $140^{\circ}F$ limit were experienced in three categories:

(a) Air-cooled surface while operating;

(b) Non air-cooled surface at any time;

(c) Any surface after shut down.

2.1 Casing temperatures while operating were, for the most part, below 140 F. Some marginal areas may be easily cooled by adding air inlets to suit or applying insulation. There appears to be sufficient cooling flow capacity (1" H_2O negative jacket static) to handle added inlets. Small problem areas exist around all jacket penetration spools owing to the direct metallic conduc-

tion from the inner casing to the outer casing. These areas too are amendable to some cooling by more localized air inlets. However, the more certain approach is to shield the penetrations with a secondary cover. The latter approach seems effective on the sewage nozzle hatch and should be applied to the firebox viewport. As a further precaution, an added layer of insulating material can be installed on either inside or outside of the outer casing.

2.2 Nonjacketed areas where overheating occurs are the feed door and the front face of the firebox. Aside from personnel safety, temperatures should be lowered for operating reasons. The feed door, presently ineffectively air-cooled, should be modified to forced air-cooling with input either from the combustion air fan or a separate source. The door output may either be discharged against the front firebox panel if cooling capacity remains or routed into the jacket if too hot. Furthermore, the door lining, presently heavy weight castable, should be replaced by high temperature insulating castable. Door temperature, presently 250° F, should be lowered to 140° F or less.

The front firebox panel problem is largely the result of locating the door in close proximity to the firebox shell, so that intense radiant heat is absorbed when the door is operated in addition to its normal, internally generated heat load. The straightforward solution to this problem is the inclusion of a tunnel section between the firebox face and the door face. Ideally, a 6 inch long tunnel section should be sufficient to eliminate the problem. The constraint, however, is that the tunnel length, plus ram provision for clearing it would require a 1 foot reduction in the firebox length if the 8 foot overall is held. It would seem more reasonable to compromise the 8 foot specification rather than reduce firebox volume so drastically. An intermediate trade off is also conceivable. Special air-cooling provision, such as mentioned with the feed door, might be applied with a smaller face clearance; say 3 inches.

2.3 The use of heavy refractory in Phase II has substantially extended the time required for the unit to cool off after burn down.

In order to limit the operating day, it has been necessary to allow only about 1-1/2 hours for cool down; which is equivalent to automatic shut down at an indicated firebox temperature of about 600° F. When shut off occurs at this temperature, heat

continues to soak into the jacket, raising its temperature substantially over 140° F. It is estimated that a cool down period of 2-3 hours would be necessary to reduce the firebox to about 400° F, sufficient to insure that the jacket remains under 140° F.

While it may be argued that the cool down period should not be considered operating time since it is unattended, some direct possibilities for alleviating the problem are as follows:

(a) Operating the sewage spray system from a separate, salt water supply from burn down to shut off. (Also desirable for maintenance flushing).

(b) Venting the top of the jacket directly to the stack by automatic damper after shut off.

(c) Opening fully the ash door, ash door hatch, and both undergrate hatches on burn down.

(d) Insulation of the outer casing panels.

3.0 Power Loss Contingencies

3.1 Loss of Compressed Air

In case (a), the loss of compressed air would constitute no hazard but simply lock out solid and sewage feed functions in a safe manner.

In case (b), it is less likely but conceivable that a massive and instantaneous loss of air could leave a full load of combustibles partially charged with the feed door falling by gravity, or the charge and lid opening obstructed by the ram mechanism. Fire would obviously progress to the hopper load.

A solution to this type of emergency would be to connect compressed air cylinders into the ship's air supply line via a 3-way valve for manual or automatic operation. Standby air in conjunction with the existing manual override capability of all cylinder valves guaranties mechanical operating capability under all service loss conditions.

3.2 Loss of Electric Power

If the above recommendation is implemented, no distinction

need be made between case (a) and case (b).

In both cases, it is assumed that appropriate alarms will be sounded and countermeasures applied. For example, if the outage is of short duration of up to 5 minutes, no severe problems are likely to develop, however, the unit must be manually restarted as soon as power is available, or conditions will approximate the effect of a longer term outage.

An obvious safeguard would be to provide an automatically coupled separate power source. If this is not considered feasible, the worst case to be visualized would be a situation which would produce gas flow out of the firebox and into the compartment via feed door clearance, burner and fan openings and undergrate openings. A smoke hazard may be involved and also heat and flame reaching stored trash or burner oil supply lines. The possibility for such reverse flow is possible if the relative pressure conditions of the compartment ventilating system is negative as compared to the stack discharge system in the unpowered condition.

If this situation can exist, it would seem wise to provide for automatic closing of compartment ventilation inlet dampers on loss of positive ventilation pressure. Similar adverse pressure differential may exist between the compartment and the companionway, thus setting up reverse flow when or if the compartment hatch is opened. Although no solution to the smoke problem, it would appear that the most direct approach to fire hazard is to install fusibly linked sprinklers in the compartment. Some protection may be also obtained by installing a normally open (closed-power on) dampered by-pass around the I. D. fan and fly ash collector.

SECTION VI
REVIEW OF DEVELOPMENT PROGRAM

1.0 Redesign Program

The rational for Phase II design improvement was based both on Phase I operating experience and on more stringent requirements of the Phase II RFP.

The following is a listing of the major Phase I subsystems, their operational disadvantages and the design remedies committed to Phase II in the order of design change priority. The ultimate Phase II design reflects the necessary trade-off consistent with the priorities indicated:

1.1 Gas Processing System

Fans

(a) Phase I Problem: Fan noise, vibration, draft deficiency, bearing failure.

(b) Phase II Remedy: Larger conventional centrifugal heat fan running at half the Phase I speed, fan deck mounted and acoustically shielded; change smaller blowers from pressure type to volume type; connect fan inlets directly to jacket casing (change jacket cooling circulation from positive to induced) to muffle inlet air noise.

Fly Ash Collector

(a) Array of three 10 inch elements evidently not efficient; cast iron mild steel construction and quality unsatisfactory. Design configuration not suitable to varying compartment layouts.

(b) Phase II Remedy: Package 26 x 3 inch elements in round vertical configuration with rotatable inlet-outlet relationship; materials all to be 316 stainless steel.

1.2 Burners

Main Burner

(a) Phase I Problem: Numerous flame outs, difficulty in diagnosing flame outs.

(b) Phase II Remedy: Change scanner chassis type from .8 sec to 2.4 sec flame interruption lock out interval; change scanner sighting to straddle both high and low fire effectively; install scanner output meter and diagnostic readouts to delineate scanner malfunction from burner system malfunction; air purge sighting tube.

*Afterburner

(a) Phase I Problem: Flame instability at high draft; frequent flame out; scanner deterioration due to heat.

(b) Phase II Remedy: Recess burner face further away from high-velocity flameport; change from photocell to cadmium cell type scanner; (higher heat rating; longer interrupted flame lock out interval).

1.3 Combustion Area and Volume

Solids

(a) Phase I Problem: Virtually continuous feeding required to meet burn rate. NSWC batch test demonstrated batch capacity about 50 lbs/hr minimal doubling of grate area and volume indicated.

(b) Phase II Remedy: Firebox area and volume increased more than 2-1/2 times by using maximum length available (8 ft) for feeder-firebox function; firebox width increased by 9 inches.

Sewage

(a) Phase I Problem: Wetting of refractory and drippage; low chamber temperature at 20+ gph; unable to maintain 40+ gph capacity; higher temperatures, more volume and longer spray stream run indicated.

(b) Phase II Remedy: Spray volume increased five-fold by dedicating entire upper part of firebox to sewage burn; separation accomplished by integral air-cooled roof slab; spray run increased four-fold by recessed horizontal nozzle configuration; burner to provide heat according to sewage burn demand (sewage chamber T. C. control).

*Subsequently deleted

1.4 Solids Feed Apparatus

Feeder

(a) Phase I Problem: Lightweight; all sheet metal design difficult to fabricate accurately; sheet metal hopper nose prone to heat distortion; lid distortion from hopper fire.

(b) Phase II Remedy: Heavier, more rugged design, using hopper through slabs and structural framing with heavy sheet metal skin.

Feed Door

(a) Phase I Problem: Door too hot (350° - 400°) due to inadequate insulation for unanticipated flame impingement from main burner.

(b) Phase II Remedy: Angle main burner away from door; double insulating value of door material; provide air-cooled door face towards hopper.

Ash Door Configuration

(a) Phase I Problem: Subject to heat deterioration due to thin planner design and burning ash in drawers; positive pressure in ash chamber.

(b) Phase II Remedy: Use radial segment design to maximize insulation thickness while minimizing exposed metal for same dimentional limits; maintain undergrate and ash chamber at negative pressure by designed ash door clearance and lower hatch air louvres.

1.5 Sewage Spray Apparatus

(a) Phase I Problem: Corrosion of 316 S.S. nozzle and piping; nozzle (1/8") plugging; inadequate nozzle assembly insulation and cooling; inadequate atomizing air.

(b) Phase II Remedy: Design injector immediately behind tip for best atomization with largest internal/tip porting (1/4") and encapsulate complete assembly in insulated billet recessed in wall refractory; provide minimal cooling air flow at all times; all assembly to be Hastalloy C; use 10 CFM atomizing air.

2.0 Incinerator Construction

Phase I construction was essentially a small welded firebox with appended lightweight ducting. Refractory casing was simplified by multiple turnings of the firebox only. However, a distinct change was indicated for Phase II to meet the following new requirements:

(a) NAVSEC's desire for "knock-down" capability, including modular size and weight limitations.

(b) NAVSEC's desire to use heavy weight refractory throughout.

(c) Increased volume and weight of the firebox module as postulated under para 1.0.

For these reasons, bolted, precast panel type construction was used throughout and proved to be quite practical in spite of the following difficulties:

(a) Shell metalwork originally specified to be 3/16" plate had to be reduced to 10 ga. sheet metal in order to accomodate the fabricator's tooling to panel flanging specifications. This made the total metalwork 600 lbs lighter. Furthermore, a good deal of time had to be spent straightening and stiffening the panels to suit before casting.

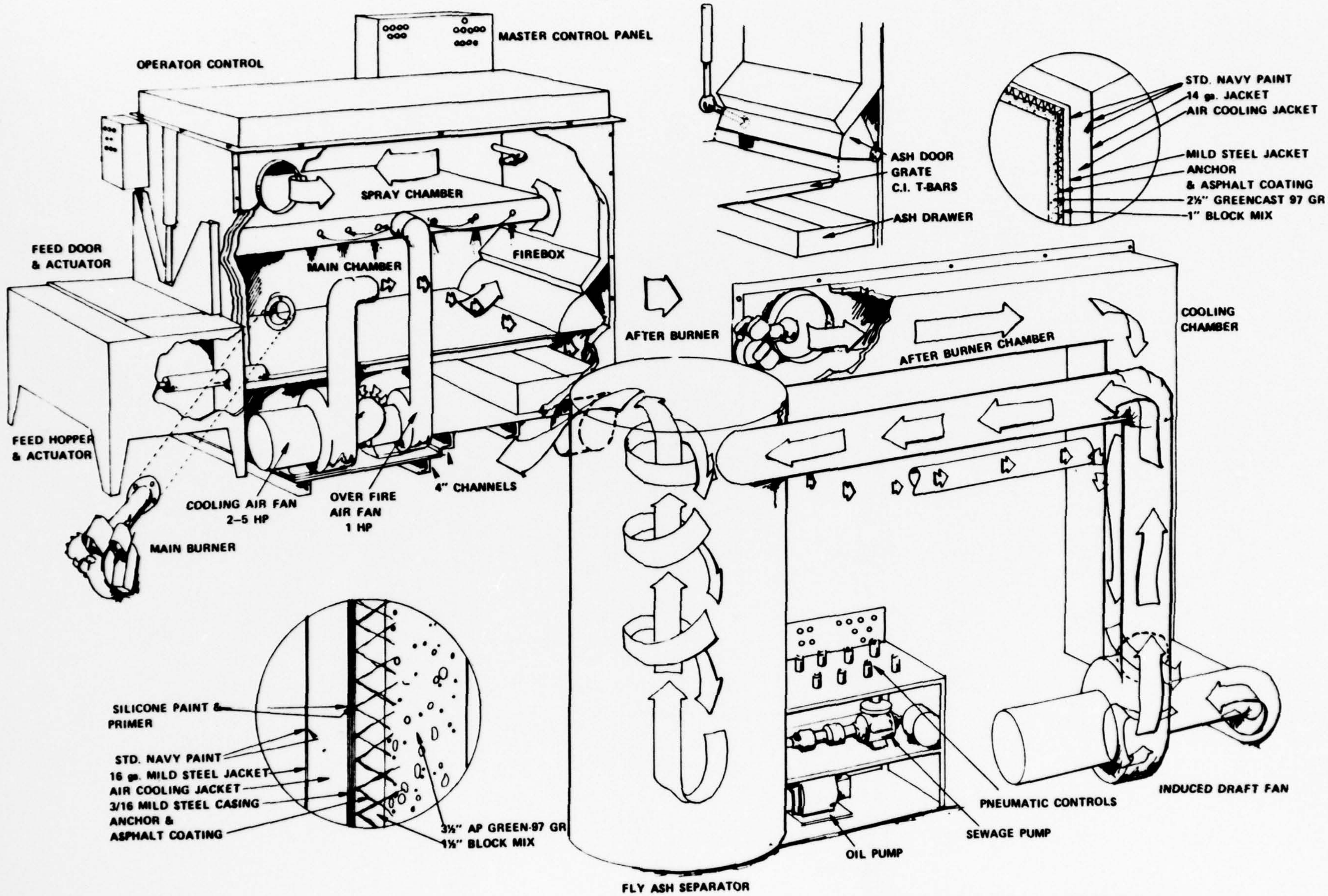
(b) Panel design was generally predicated on the assumption that refractory at 90 lb/cft was to be used. A midstream change to refractory at 160 lb/cft presented many problems in cast form work, casting setup and assembly. The difficulty in maintaining dimensional integrity may be appreciated when visualizing that on general precast panels 150 lbs of metal supported 1000 lbs of refractory.

Projecting ahead to multi-unit production, it is believed that construction can be reduced to an economical routine for this type of structure. On the other hand, the practicality of the modular panel concept is yet to be proven on the projected scaled-up version.

3.0 Incinerator Design

3.1 Function

The functions of the incinerator are illustrated on the Functional Schematic, Fig. 3 and may be summarized as follows:



ARTIST'S SKETCH OF PHASE II INCINERATOR

Fig.3

Charging Procedure

The operator loads the FEED HOPPER of the RAM FEEDER with refuse or trash and actuates the FEED RAM via a push-button. The FEEDER DOOR opens and allows the refuse to be introduced into the MAIN CHAMBER. The feed system is under timer control and permits the operator to charge up to 126 lb within five minutes (equivalent to 3-5 charges). The refuse is allowed to burn for 55 minutes before the feeder is automatically released for a fresh charge.

Burn Function

The solid waste supported by a cast-iron grate in the main chamber burns with the assistance of the MAIN BURNER. Temperature in the main chamber is automatically controlled by a temperature controller. The main burner may burn light fuel oil or waste oil. Selection may be made by a simple push-button operation.

Sewage is injected into the SEWAGE CHAMBER through an air-atomizing SEWAGE NOZZLE. To insure complete vaporization, a low-temperature limit control insures the sewage is introduced only while the temperature is above 850 F.

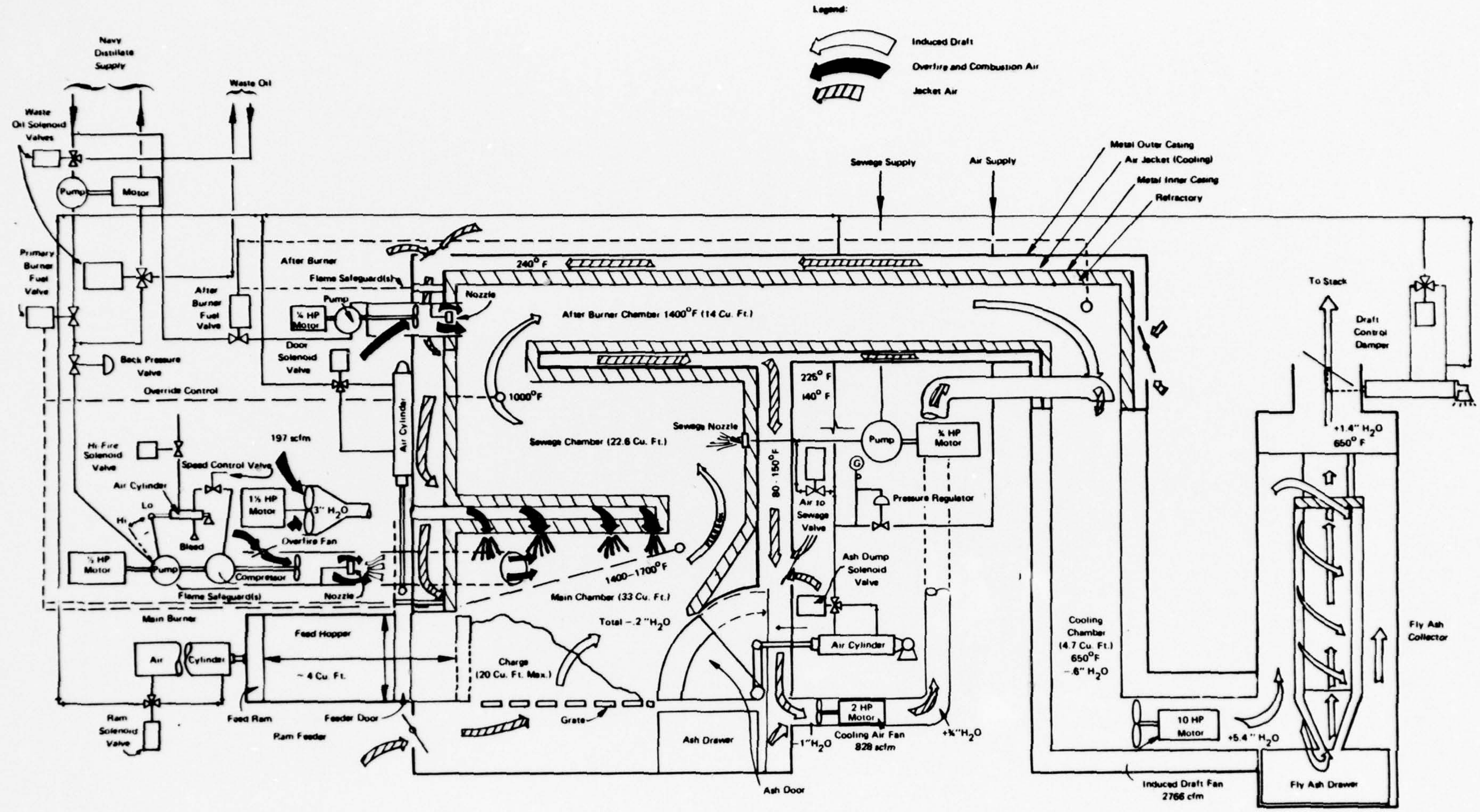
To insure complete smokeless and odorless combustion, the products of combustion including the vaporized sewage pass through the AFTERBURNER CHAMBER where the AFTERBURNER maintains a temperature of 1400 F. (Eliminated from prototype as shipped)

Gas Flow

Air for combustion is supplied under the fire by natural draft and over the fire from a combustion air fan through a nozzle matrix located in the roof of the main chamber. In addition, air is provided by the main burner through its own integrally-mounted air fan.

3.2 Configuration

The final design of the incinerator configuration is illustrated in the Artist's Sketch shown in Fig. 4. It shows the physical arrangement of the major components as well as the method of construction used.



FUNCTIONAL SCHEMATIC
PHASE II INCINERATOR

Fig.4

Firebox

The top left view shows the FEED HOPPER and FEED DOOR attached to the FIREBOX. Located at the operator eye-level is the OPERATOR CONTROL PANEL with the technician's MASTER CONTROL PANEL mounted on a bulkhead. The location of the MAIN BURNER COOLING AIR FAN and OVERFIRE AIR FAN are shown.

Details of the ASH DOOR, GRATE BARS and ASH DRAWER arrangement may be seen in the right top center.

Gas Passage

The gases move from the MAIN CHAMBER to the SPRAY or SEWAGE CHAMBER through the FLAME PORT to the AFTER-BURNER CHAMBER which, though shown in the right hand corner, is directly attached to the FIREBOX. The COOLING CHAMBER, INDUCED DRAFT FAN and FLY ASH SEPARATOR are shown in their respective positions.

Construction

Firebox construction is detailed in the bottom left circle. It is seen to consist of 3-1/2 in. of A. P. Green Greencast 97GR backed up by 1-1/2 in. Block Mix. 310 stainless steel anchors secure this lining to the 3/16" mild steel jacket which is protected with a ceramic silicone coating. The outer casing consists of 16 gage mild steel panels painted with standard haze-grey Navy paint.

The construction of the afterburner chamber may be seen in the top right hand circle. It is similar in construction as the firebox except that the inner lining consists of 2-1/2 in. Greencast 97GR backed up by 1 in. Block Mix.

Miscellaneous

Various other auxiliary equipments such as the sewage pump, oil pump and pneumatic controls are mounted on a separate rack which may be secured to a bulkhead.

Overall Size

The incinerator occupies about 64 sq ft with a height of 7 ft. The whole system including control panels and auxiliaries

is so designed that it may be fitted and maintained in any compartment with a floor area of 144 sq ft and a celing height of 8 ft. Total power requirement is 15 KW.

The whole unit is air-cooled by means of an AIR JACKET to insure a safe skin temperature of 140 F. Cooling air is drawn into this jacket by the COOLING AIR FAN and exhausted into the COOLING CHAMBER. In this chamber, the hot gases from the afterburner chamber are mixed with the jacket air resulting in a gas mixture at a temperature of 650 F.

An INDUCED DRAFT FAN draws the gases at a negative pressure from the unit and blows them at a positive pressure into a centrifugal FLY ASH COLLECTOR from which they pass up the stack.

Ashes

While charging, the ASH DOOR opens allowing the fresh charge to push the residue into the ASH DRAWER. Ashes are removed once a day before a new burn is commenced.

In addition, ash siftings falling through the grate openings are accumulated in the undergrate chamber and are removed once a week.

Fly ash from the fly ash collector is collected in the FLY ASH DRAWER. Once weekly clean-out is required.

Environmental Conditions

The unit is designed to operate safely and within the required noise specifications. Skin temperatures are maintained below 140 F and the noise level is less than Category D (MIL-STD-740B (SHIPS)) less 10db. Emission is essentially smokeless and particulates are controlled below 0.2 gr/scft for trash and 0.5 gr/scft for sewage (both corrected to 12% CO_2).

APPENDIX

50 Moulton Street
Cambridge, Mass. 02138
Telephone (617) 491-1850

Bolt Beranek and Newman Inc.

January 20, 1977

Vent-O-Matic
P.O. Box 157
North Quincy, Mass. 02171

Attention: Mr. Charles Mark

Dear Mr. Marks,

As you know, on 28 December 1976 we had an opportunity to test your Navy M.F.I. incinerator system in a completed configuration; i.e., with all lagging and covers in place, tight, and completed. An initial test was run with the sewerage slurry pump on (in table 1). It was noticed that the gear pump for the sewerage injection system, which is not considered to be part of the incinerator (at least for the noise test program) seemed to be adding some noise in the mid-frequency bands. As you will recall, it was these bands that were somewhat over the specified levels in the previous two tests.

A second test series was run because of this with the sewerage pump shut down and the data seen in table 2 resulted. In this test, the unit was being run on normal fire and the incinerator was being operated in a normal mode (with no sewerage feed). We are pleased to inform you that when sound power levels are computed on the basis of ANSI spec S1.2, Sec. 3.4 [sound power levels in a free field above a reflecting plane], the unit meets the specified noise levels in all but two bands. In these two bands (500 and 1000 Hz), the incinerator is only 1 dB over the spec.

Sound Power Level in dB re 10^{-12} Watts

	31	63	125	250	500	1K	2K	4K	8K	Hz
Test results	92	96	96	94	88	83	78	71	67	
Spec requirement	112	107	102	97	87	82	82	82	82	
dB over spec					1	1				

These results are plotted on figure 1. Figure 2 is a plan view of the test set up and identifies measurement locations.

As stated previously, the test procedure being used is the most stringent one (the one that may give the highest answers) from Vent-O-Matic's point of view. The space in which the measurements were made is not a true free field. However, since we did not get the room calibrated prior to testing, this is the most nearly correct procedure available to us at this time. It is our considered opinion that in the bands in question, i.e., the 500 and 1000 Hz bands reflected acoustic energy from the walls could be adding at least 1 dB to the power levels. If that is so, the unit's true power level will meet the specification. In addition, the deck the unit sits on is quite mobile and appears to be quite easily excited at these induced draft blower frequencies. With a harder, stiffer, less responsive floor, the contribution from the fan vibration levels would decrease. Based on the considerations of the test methods used and the mobile nature of the mounting floor, it is our considered opinion that this unit will meet the specification when tested in a final installation, all other things being equal.

With reference to the specification noise tests to be made at the Navy's establishment, it is our recommendation that a couple of things be done to legitimately enhance the odds in Vent-O-Matic favor. To this end, we strongly suggest that Vent-O-Matic make sure the Navy properly calibrates the test space prior to testing. We would suggest the use of the "semi-reverberant field" test procedure as specified in ANS1 S1.2 section 3.6.

Further, we would recommend that in the area of induced draft blower, its plenum and the fly ash collector, resilient rubber pads, known in the Navy circles as DIM (distributed isolation media) be installed between the feet or bases of these units and the deck. The material we recommend here would be one made by Barry Corporation of Watertown Mass. and is specifically called "30005 Mounting Pad". It should be installed in such a manner that it is loaded at about 65 lb/ sq. in.

We hope that this very short letter test report is sufficient. Should there be any questions or comments, please let me hear from you.

Sincerely,

Arial W. George

Arial W. George
Senior Scientist
BOLT BERANEK AND NEWMAN INC.

AWG:mac

bbn

BOLT BERANEK AND NEWMAN INC

CONSULTING · DEVELOPMENT · APPLIED RESEARCH

JOB 10945

DATE 28 December 1976

SHEET 1 OF 1

ENGINEER Arial George

Vent-O-Matic Incinerator re-lagged and Cover Over Fan Drive

DESCRIPTION	OCTAVE BAND CENTER FREQUENCY IN CPS										TIME
	OA	31.5	63	125	250	500	1000	2000	4000	8000	
Sewage Pump On					TABLE I						
Front	89	71/73	78/81	84	83	76	73	68	60	54	
Left	89	82	81	82	80	75	73	68	61	57	
Back	89/91	79/82	84	84	80	76	73	66	59	53	
Top	86	74/79	78	83	79	69	67	60	53	49	
Right front	90	74/78	77	87/88	86	77	73	68	61	58	
Right back	91	78/80	78	82	86	77	69	64	57	53	
Sewage Pump Off					TABLE II						
Front	89	69	79	82	81	73	67	64	56	51	
Left	86	78	79	80	78	73	68	62	56	49	
Back	—	80	85	84	81	74	68	53	56	51	
Right back	91	82	86	84	84	75	70	65	58	53	
Right front	89	74/78	81	84	81	77	73	69	62	59	
Front	88	77	81	80	81	75	71	66	58	51	
Top	89	74/78	81	80	77	74	68	64	55	52	

BBN 020-20 2/70

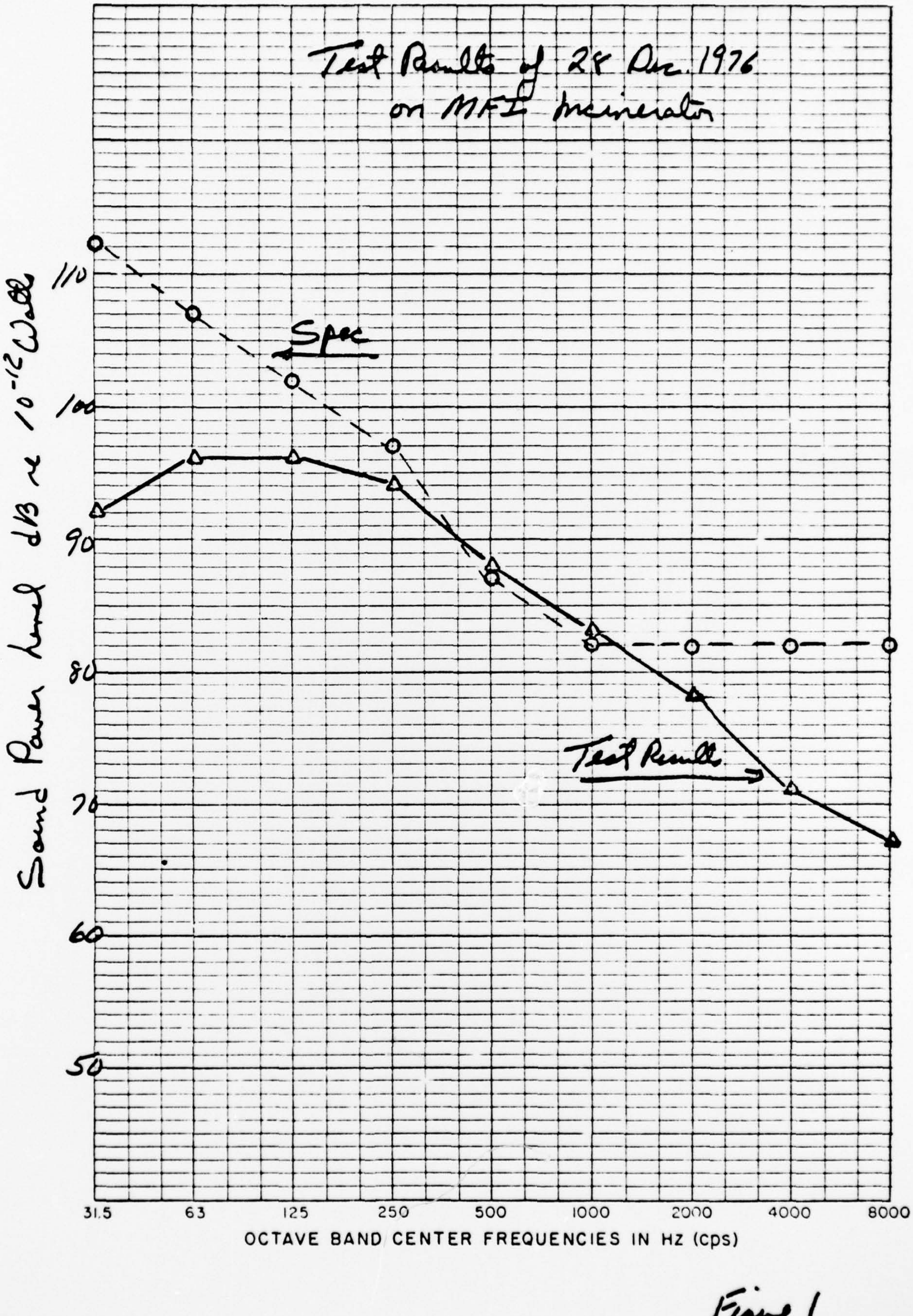

Test Results of 28 Dec. 1976
on MFI Incinerator
Spec
Test Results
Sound Power Level dB re 10^-12 Watts
110
100
90
80
70
60
50
31.5
63
125
250
500
1000
2000
4000
8000
OCTAVE BAND CENTER FREQUENCIES IN Hz (cps)

Figure 1

BOLT BERANEK AND NEWMAN INC

CONSULTING DEVELOPMENT RESEARCH

Boston Washington Chicago Houston Los Angeles San Francisco

JOB 12945

DATE 29 Dec 76

SHEET 1 OF 1

CNSLTNT RW George

Vent-O-Matic incinerator noise ~~test~~

Test locations on MFI incinerator

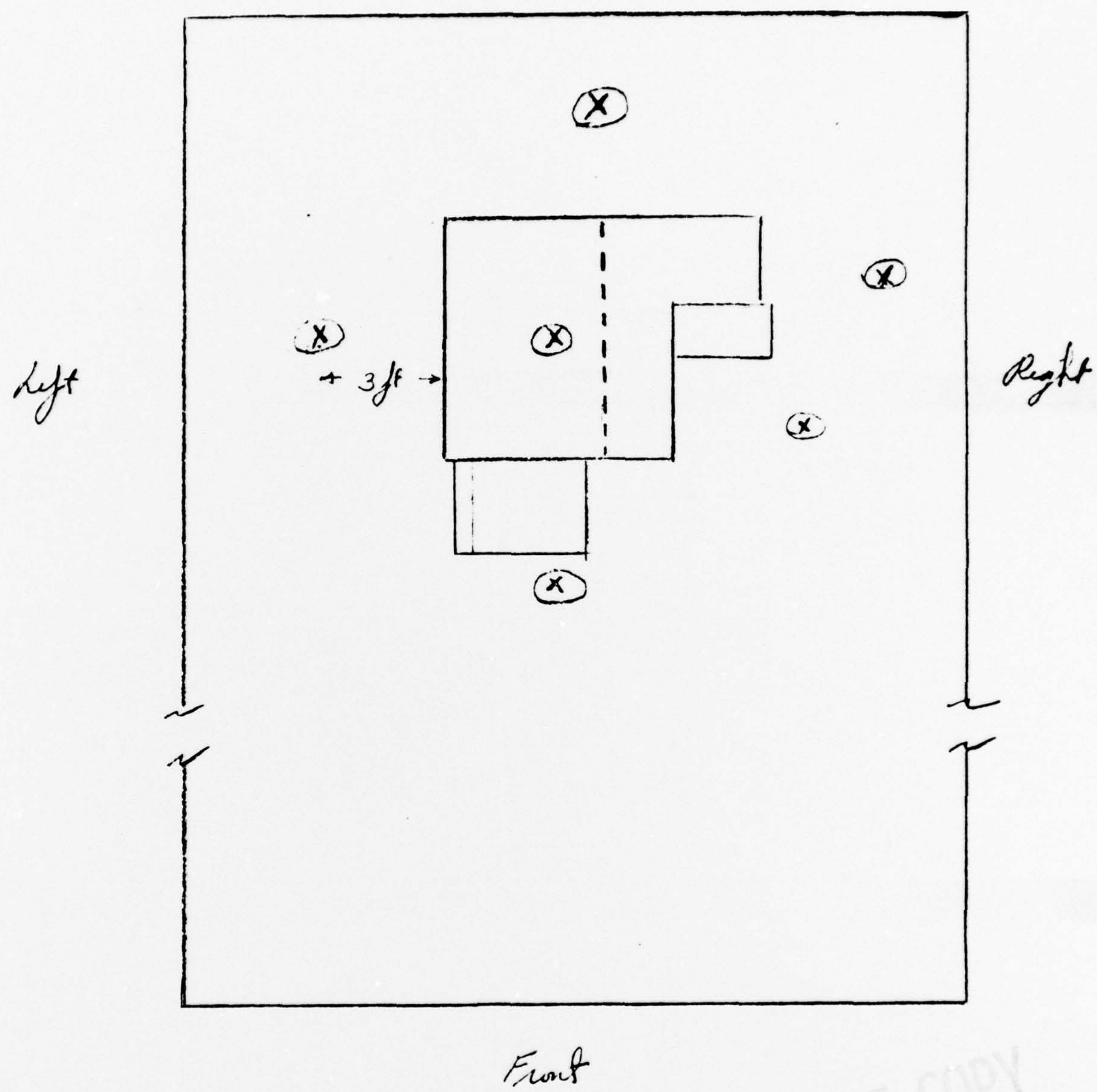


Figure 2

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

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S46-X1 Task 17384

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Incinerator	Refuse
Shipboard Waste	Garbage
Shipboard	Oily Waste

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report covers the second phase in the design and development program of a new multi-functional incinerator (MFI System).

The incinerator is designed to fit into a compartment 12 ft x 12 ft x 8 ft. The system consists of seven modules which may be arranged to suit the compartment lay-out. The total system weight is 1400 lb. →

(continued)

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New features of the Phase II incinerator include the following: --

- flat blade centrifugal induced draft fan in place of duct-type axial flow,
- heavy castable refractory throughout,
- larger firebox volume,
- heavier feeder construction,
- small diameter multi-tubular fly ash collector,
- semi-automatic feeder control, and
- diagnostic monitoring circuit on burner control.

The MFI System was fabricated, assembled and tested. The report describes problems encountered, corrective action taken and recommendations for modifications on subsequent units.